

ON THE VOLUME AND SURFACE RESISTIVITIES OF SHELLAC MOULDED MATERIALS

By G. N. BHATTACHARYA

(Received for publication, November 10, 1947)

ABSTRACT The volume and surface resistivities of a number of shellac moulded discs of different composition have been determined by the electron tube method using a Philips 4060 electrometer triode. Mercury electrodes were used and most of the determinations were made at a constant potential of 150 volts. The effects of humidity and temperature were also studied and the results have been shown in a number of diagrams. "Shellac plastics may, as a result of this investigation, be safely classed among those materials which have a high value of volume and surface resistivity.

INTRODUCTION

The direct-current resistance of an insulating material is usually determined by applying a potential difference between two points on the material and measuring the feeble current by any suitable means. But this resistance is usually considered to be the resultant of two components, *viz.*, the volume resistance and the surface resistance. Curtis¹ devised an ingenious apparatus to measure these two resistances separately by means of guard rings and his method of test has been adopted by the British Standards Institution² for determining the surface resistivity of moulded insulating materials. The American Society for 'Testing Materials' has also adopted a similar apparatus for the determination of the two resistivities. But if the resistivities are very high, the measurement of the extremely small current in this method may sometimes involve some difficulty, since this current is often so small that it is difficult to measure it even with a sensitive galvanometer. The method of charging a condenser with the feeble current and discharging it through a ballistic galvanometer has been described by Brown⁴ and others⁵ in high-resistance circuits, but the limitations of this method, the most troublesome of which is the long time constant, have been fully discussed by Cherry.⁶ An electrometer (Compton⁷ or Lindemann⁸) may be used for this purpose, but this method has also several disadvantages which have been described by Müller⁹ and Cherry.⁶ At present the electron tube method¹⁰ is perhaps the most sensitive method of measurement in such a case. For this purpose special vacuum tubes called electrometer tubes are being used now. Rose¹⁰ has described a circuit which makes use of the plotron FP-54 of the General Electric Company of America for the measurement of very high resistances. Other investigators¹¹ have also used this tube in different circuits but Müller¹² and Cherry⁶ for simplicity used triodes and their circuits have been fully described. With the help of such a circuit the value

of the unknown high resistance R_x may be obtained in terms of another known high resistance R_s , the applied voltage E and the potentiometer voltage e required for balance. The relation¹³ is

$$R_x = R_s [(E/e) - 1].$$

PREVIOUS WORK

Dietrich¹⁴ studied the effect of temperature, light and moisture on the resistivity of lac. Curtis¹ measured the volume and surface resistivities of shellac along with other insulating materials. Stüger¹⁵ also studied the effect of temperature on lac, pure lac resin and shellac-wax. An excellent review of these results has been made by Verman,¹⁶ who states that both Dietrich's and Stüger's results for lac samples could by a proper choice of constants be made to fit Koenigberger and Reichenheim¹⁷ equation

$$\rho = \rho_0 \cdot e^{-qt/273(t-273)}$$

where ρ = resistivity at $t^\circ\text{C}$., ρ_0 = resistivity at 0°C ., q = a constant.

The object of this paper is to report the results of measurement of resistivities of a few shellac moulded discs of different compositions¹⁸ which have been evolved at this Institute under different conditions of temperature and humidity.

EXPERIMENTAL

As the preliminary measurements revealed that the volume and surface resistivities of shellac moulded discs were too high to be measured simply with

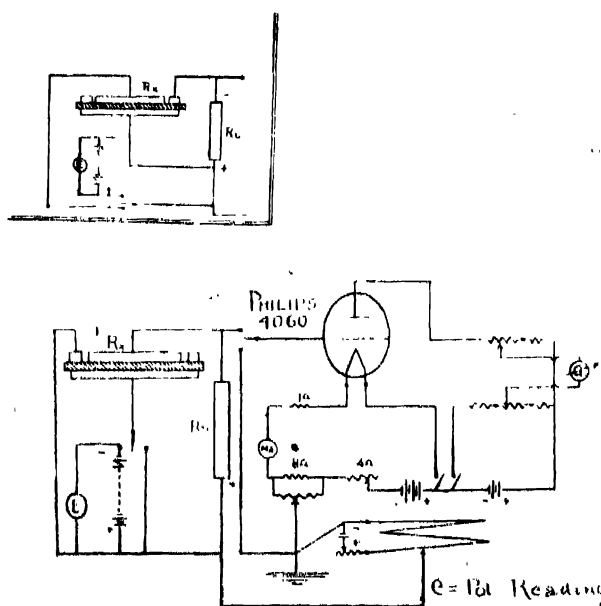


FIG. 1

Volume and Surface Resistivities of Shellac Moulded Materials 149

a galvanometer, a circuit was constructed with a Philips 4060 electrometer triode. The particulars of this tube appeared in this journal " some time back and so these are not being given again. The circuit was similar in design to that described by Cherry⁶ using the Westinghouse electrometer tube RH-507. The schematic diagram of the circuit used has been shown in Figure 1. The method of measurement and precautions regarding shielding and insulation have also been dealt by Müller⁷ and other workers²⁰ and so these need not be repeated here.

Mercury electrodes as used by Curtis¹ were used in these investigations. Most of the measurements were done at a constant potential of 150 volts. The source of this voltage was a high-tension dry battery as used for radio sets. Humidity was controlled with solutions of different proportions of glycerine and water.²¹ A big vacuum desiccator was used as the humidity chamber and tests were carried out inside this chamber. The leads were taken out through the top and holes made on the sides and closed with bushings made of beeswax-rosin. The voltage was applied across the dielectric together with a standard high resistance. A number of these standard high resistances of different values were made from liquid mixtures of alcohol, benzene, phenol and picric acid as described by Gemant.²² These high resistances were kept in a chamber which was air tight and where some desiccating agent such as fused calcium chloride was kept in order to minimise surface leakage. The potential drop across the standard high resistance was measured by means of the electrometer triode on a potentiometer.

RESULTS AND DISCUSSIONS

The results of test have been shown in Tables I-III. They have also been shown in graphical form in Figures 2-4. Table IV shows the particulars of

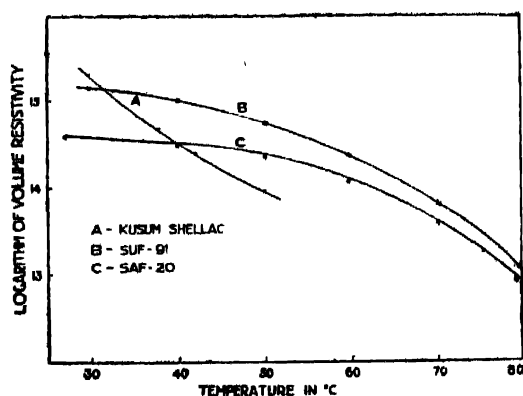


FIG. 2

composition of shellac moulded discs. The variation of volume resistivity with temperature (Fig. 2) was found greater for kusum shellac than for shellac

moulding powders (Nos. SUF-01 and SAF-20) within the small range of temperatures through which it was possible to carry out measurements. At temperatures above 50°C. shellac discs began to soften slowly and it was not possible to make measurements. But shellac-urea-formaldehyde and shellac-aniline-furfural moulded discs withstood higher temperatures and measurements were carried out up to 80°C. After 65°C. the fall of resistivity of these discs however was somewhat rapid, probably owing to slight softening.

The effect of humidity on the volume resistivity of shellac discs has been shown in Fig. 3. Measurements were carried out when the discs were desiccated

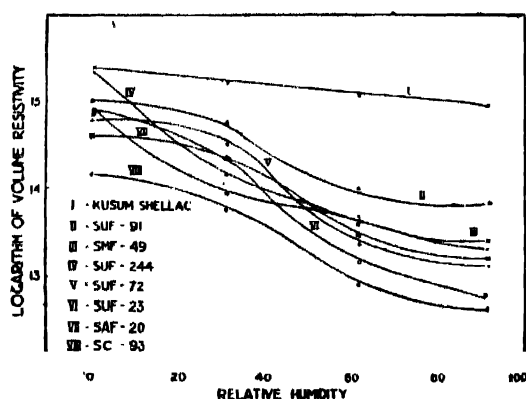


FIG. 3

and also under three different conditions of relative humidity, *viz.*, 30, 60 and 90 per cent. At each humidity the discs were kept for 72 hours before they were tested. The maximum slope of these curves seems to lie within 30 per cent and 60 per cent relative humidity indicating the maximum rate of fall. Similarly the variation of surface resistivity with humidity has been shown in Fig. 4. Here also the rate of fall is small up to 30 per cent humidity and thereafter it is more. A composition containing 10% rosin on the weight of lac (No. SUF-244; Curve IV, Fig. 4) shows a peculiarity in that the rate of decrease

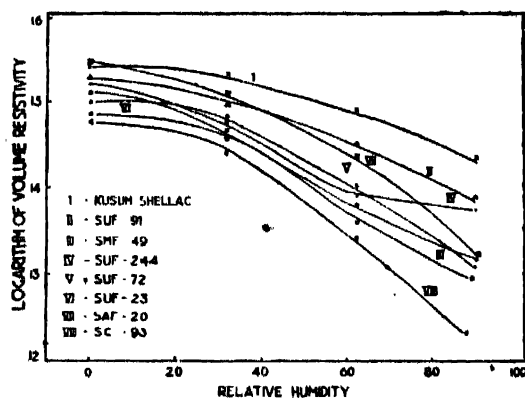


FIG. 4

Volume and Surface Resistivities of Shellac Moulded Materials 151

of surface resistivity after 60% relative humidity is very small. This may be due to the presence of rosin which has been shown by Curtis¹ to have a very low rate of fall of resistivity with increasing humidity.

It may be mentioned in this connection that the current which flows through a solid insulating material as soon as the voltage is applied does not, as is well known, remain constant but changes with time. For some purposes²³ the current at the end of one minute is taken since the absorption current is usually negligible at the end of that period. In these tests, however, the current was measured at the end of 3 minutes since it was observed in a few cases that the effect of this absorption current could be noticed even after 2 minutes. At the end of three minutes, however, the current was more or less constant and hence that could be taken as the conductivity current. It should be noted, however, that the error of such high resistance measurements may be approximately 10% or even slightly more.

It may be said that the resistivity of shellac compositions generally is very high. At 50 per cent relative humidity and ordinary temperatures (25°C.-30°C.) the volume resistivity of these compositions usually lies within 3.5×10^{13} to 2.5×10^{14} ohm-cms. A comparison with the resistivity of other moulded materials is not feasible unless all the conditions of experiment are the same, e.g., the method of measurement, the dimensions of the specimen, the applied voltage, the temperature, the humidity, etc. Nevertheless, on a scrutiny of the values of resistivity of most of the plastic materials,²⁴ shellac compositions may safely be classed among those plastics which have a very high resistivity.

TABLE I
Showing the variation of volume resistivity with temperature

ρ_v = volume resistivity.

Material	Temperature in °C	$\times 10^{13} - \rho_v$	Log ρ_v
Kusum shellac	28.4	262	15.41
	38.0	54.1	14.73
	42.6	28.0	14.44
	50.0	9.8	13.99
Shellac powder No. SUF-91	30.0	139	15.14
	40.0	95.7	14.98
	50.0	62.1	14.79
	60.0	28.9	14.46
	70.0	7.6	13.88
	80.0	1.4	13.14
Shellac powder No. SAI-20	27.0	42.2	14.62
	40.0	35.2	14.54
	50.0	21.4	14.32
	60.0	14.3	14.16
	70.0	5.1	13.7
	80.0	1.2	13.06

TABLE II

Showing the variation of volume resistivity with humidity

 ρ_v = volume resistivity.

Material	$\times 10^{13} = \rho_v$ at relative humidity			
	0	30%	60%	90%
Kusum shellac	262	150	135	80
SUF-91	103	66	12.7	8.2
SME-49	80	11	5.1	3.1
SUF-244	167	15.2	6.8	2.4
SUF-72	64	42	3.6	1.8
SUF-23	96	25	1.6	0.73
SME-20	40	26	4.4	2.1
SC-93	16	7.6	1.3	0.51

TABLE III

Showing the variation of surface resistivity with humidity

 ρ_s = surface resistivity.

Material	$\times 10^{13} = \rho_s$ at relative humidity			
	0	30%	60%	90%
Kusum Shellac	760	660	180	73
SUF-91	590	320	100	20
SME-49	380	160	14	2.5
SUF-244	480	190	24	16
SUF-72	295	216	33	3.6
SUF-23	200	140	19.6	4.2
SME-20	830	380	76	4.9
SC-93	175	113	10	0.42

Volume and Surface Resistivities of Shellac Moulded Materials 153

TABLE IV

Showing the particulars of composition of shellac moulded discs used

Disc	Resin	Filler	Percentage of		
			Resin	Filler	Dye and lubricant
Kusum Shellac	Shellac	-	-	-	-
SUF-91	Shellac-urea-formaldehyde	Wood flour	48	49	3
SMP-49	Shellac-melamine-formaldehyde	Wood flour	45	54	3
SUF-244	Shellac-urea formaldehyde with resin and Phenol	Saw-dust	60	38	2
SUF-72	Shellac-urea-formaldehyde	Mica	30	69	1
SUF-23	"	Asbestos	30	69	1
SUF-20	Shellac-aniline-furfural	Wood flour	49	49	2
SC-93	Shellac-casein	Wood flour	51	46	3

ACKNOWLEDGMENT

The author expresses his indebtedness to Dr. H. K. Sen, the Director of this Institute, for his kind interest and constant encouragement.

INDIAN LAC RESEARCH INSTITUTE,
RANCHI

REFERENCES

- ¹ Curtis, H. L., *Bull. Bur. Standards*, **11**, 359 (1914-15).
- ² B. S. Inst., *B. S. Specifications for Moulded Insulation Materials suitable for Accessories for General Electrical Insulation*, No. 488 (1933).
- ³ A. S. T. M. *Standards*, Part III, 299 (1939).
- ⁴ Brown, H., *J. Sci. Instr.*, **2**, 12 (1924).
- ⁵ Dole, M., *J. Am. Chem. Soc.*, **53**, 620 (1931); Jones and Kaplau, *J. Am. Chem. Soc.*, **50**, 1845 (1928).
- ⁶ Cherry, R. H., *Trans. Electrochem. Soc.*, **72**, 33 (1937).

- ⁷ MacInnes, A. and Belcher, D., *J. Am. Chem. Soc.*, **53**, 3315 (1931).
- ⁸ Kenidge, B. M. T., *Biochem. J.*, **19**, 611 (1925); Müller, F., *Zeit. f. Elektrochem.*, **37**, 857 (1931).
- ⁹ Müller, F., *Trans. Electrochem. Soc.*, **62**, 335 (1932).
- ¹⁰ Rose, G. M., *Rev. Sci. Instr.*, **2**, 810 (1931).
- ¹¹ Du Bridge, L. A., *Phys. Rev.*, **37**, 392 (1931); Hill, *Science*, **73**, 529 (1931);
Du Bridge, L. A., and Brown, H., *Rev. Sci. Instr.*, **4**, 532 (1931); Turner, I. A.,
and Siegelin, C. O., *Rev. Sci. Instr.*, **4**, 429 (1933).
- ¹² Müller, F., *Zeit. f. Elektrochem.*, **38**, 418 (1932).
- ¹³ Littleton, J. T., and Morev, G. W., *The Electrical Properties of Glass* (J. Wiley & Sons), 67 (1933).
- ¹⁴ Dietrich, W., *Phys. Zeit.*, **11**, 187 (1910).
- ¹⁵ Stager, H., *Elektrotechnische Isoliermaterialien* (Wiss. Verlag, Stuttgart), 210 (1931).
- ¹⁶ Verman, L. C., *Lond. Shell Res. Bur. Tech.*, Paper No. 7, May (1936).
- ¹⁷ Koenigberger and Reichenheim, *Phys. Zeit.*, **7**, 570 (1906); *ibid*, **8**, 833 (1907); *ibid*, **9**, 351, (1908); *Zeit. f. Elektrochem.*, **15**, 7 (1909).
- ¹⁸ Bhattacharya, G. N., *Paper under Publication*. Venugopalan, M., and Sen, H. K., *British Plastics & Moulded Products Trader*, **10**, 626 (1939); Sen, H. K., *J. Ind. Chem. Soc.*, **18**, 47 (1941).
- ¹⁹ Thaer, J. A. N., *Ind. J. Phys.*, **13**, 199 (1939).
- ²⁰ Fosbinder and Schoonover, *J. Bio. Chem.*, **88**, 605 (1930); Jaussen, *Chem. Weekbk.*, **28**, 218 (1931).
- ²¹ Grover, D. W. and Nicol, J. M., *J. Soc. Chem. India*, **89**, 175 (1940).
- ²² Gemant, A., *Liquid Dielectrics* (J. Wiley & Sons), 66 (1933).
- ²³ A. S. T. M. Standards, Part III, 304 (1939), and B. S. Specifications, No. 488, 14 (1933).
- ²⁴ Modern Plastics, **17**, *Plastics Properties Chart*, 1939-1940, Oct. (1939).